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A TRANSFER OF FUNCTIONS THROUGH DERIVED ARBITRARY AND NONARBITRARY STIMULUS RELATIONS

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During Experiments 1 and 2, subjects were trained in a series of related conditional discriminations in a matching-to-sample format (A1-B1, A1-C1 and A2-B2, A2-C2). A low-rate performance was then explicitly trained in the presence of B1, and a high-rate performance was explicitly trained in the presence of B2. The two types of schedule performance transferred to the C stimuli for all subjects in both experiments, in the absence of explicit reinforcement through equivalence (i.e., C1 = low rate and C2 = high rate). In Experiment 2, it was also shown that these discriminative functions transferred from the C1-C2 stimuli to two novel stimuli that were physically similar to the C stimuli (SC1 and SC2, respectively). For both these experiments, subjects demonstrated the predicted equivalence responding during matching-to-sample equivalence tests. In Experiments 3 and 4, the conditional discrimination training from the first two experiments was modified in that two further conditional discrimination tasks were trained (C1-D1 and C2-D2). However, for these tasks the D stimuli served only as positive comparisons, and ND1 and ND2 stimuli served as negative comparisons (i.e., C1 × ND1 and C2 × ND2). Subsequent to training, the negatively related stimuli (ND1 and ND2) did not become discriminative for the schedule performances explicitly trained in the presence of B1 and B2, respectively. Instead, the ND1 stimulus became discriminative for the schedule performance trained in the presence of B2, and ND2 became discriminative for the schedule performance trained in the presence of B1. All subjects from Experiment 4 showed that the novel stimulus SND1, which was physically similar to ND1, became discriminative for the same response pattern as that controlled by ND1. Similarly, SND2, which was physically similar to ND2, became discriminative for the same response pattern as that controlled by ND2. Subjects from both Experiments 3 and 4 also produced equivalence responding on matching-to-sample equivalence tests that corresponded perfectly to the derived performances shown on the transfer of discriminative control tests.

Key words: stimulus equivalence, transfer of functions, S+ relations, S− relations, arbitrary relations, physical similarity, complex time-based reinforcement schedules, typing, key press, humans

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After a discriminative response is explicitly trained to one member of an equivalence class, that same response may then transfer to the other members of the class without additional training. A number of recent studies have demonstrated this form of transfer of control through equivalence classes using, for example, clapping and waving (Hayes, Devany, Kohlenberg, Brownstein, & Shelby, 1987), conditional ordering (Wulfert & Hayes, 1988), simple simultaneous discriminations (de Rose, McIlvane, Dube, & Stoddard, 1988), and conditional matching to sample (Gatch & Osborne, 1989; Hayes, Kohlenberg, & Hayes, 1991; Kohlenberg, Hayes, & Hayes, 1991) as discriminative responses.

Interestingly, these studies suggest that equivalence procedures might also be useful for examining important aspects of stimulus control in the context of reinforcement schedules. For example, in two recent studies (de Rose, McIlvane, Dube, Galpin, & Stoddard, 1988; de Rose, McIlvane, Dube, & Stoddard, 1988) subjects were exposed to a simple concurrent fixed-ratio 1 (FR 1) extinction (EXT) schedule, in which one stimulus (A1) was established as an S+ and a second stimulus (A2) was established as an S−. Following matching-to-sample training in which choosing B1 was reinforced in the presence of A1 and choosing B2 was reinforced in the presence of A2, the S+ and S− functions transferred to B1 and B2, respectively, in the absence of any additional explicit reinforcement. Further-

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more, those subjects who were then trained to select B1 given D1 and B2 given D2 showed a transfer of S+ and S− functions, through symmetry (e.g., B1-D1) and transitivity (e.g., A1-B1-D1) to the D1 and D2 stimuli, respectively.

Although these findings support the idea that discriminative functions derived through equivalence may control human performance on the simplest of reinforcement schedules, there has been no published research that has demonstrated a transfer of control through equivalence over responding produced on more complex, time-based schedules. In the one study that did employ complex schedules (i.e., random-interval schedules arranged for completion of either differential reinforcement of low rates or differential reinforcement of high rates), the single subject demonstrated a transfer of control through symmetry but was not tested for a transfer of control through transitivity, due to time constraints (Catania, Horne, & Lowe, 1989). The first experiment presented here examines whether subjects trained in four conditional discriminations (i.e., A1-B1, A1-C1, A2-B2, A2-C2) and trained in two discriminative functions on complex schedules (i.e., B1 = low rate and B2 = high rate) will show a transfer of functions through symmetry (e.g., B1-A1) and transitivity (e.g., B1-A1-C1) to the C stimuli (i.e., C1 = low rate and C2 = high rate).

These procedures can be readily adapted to examine the combined effects of stimulus equivalence and the nonarbitrary relation of physical similarity. Only one published study has addressed this issue (Fields, Reeve, Adams, & Verhave, 1991). In this study, subjects were trained in two three-member equivalence classes (AB and BC) in which the A and B stimuli were nonsense syllables and the C stimuli were sets of short or long lines. The equivalence and physical similarity test involved presenting novel line lengths as samples with the A stimuli as comparisons; the probability of selecting a given comparison was shown to be an inverse function of the difference in the length of the test line from the training line. Although this study clearly showed a transfer of conditional discriminative functions through equivalence and physical similarity, the training and test phases both involved matching-to-sample tasks. No published research has yet demonstrated a transfer of stimulus functions through equivalence relations to physically similar stimuli in which the transfer of control test involves a task that differs from the matching-to-sample procedure. It is possible, therefore, that equivalence and physical similarity will interact to control novel behavior only when training and test performances are all conducted within the context of the same type of task. To address this issue, Experiment 2 of the current study examined a transfer of discriminative functions through equivalence and physical similarity to performance on complex reinforcement schedules (i.e., on a non-matching-to-sample task). This experiment was identical to Experiment 1, except that additional transfer of control test trials were included that tested the stimulus functions of two novel stimuli, SC1 and SC2, that were physically similar to the C1 and C2 stimuli, respectively. That is, the derived stimulus functions of C1 and C2 were expected to transfer to SC1 and SC2, respectively (i.e., SC1 = low rate, SC2 = high rate).

In the investigation of stimulus equivalence, researchers have tended to focus on the way in which stimuli become positively related to each other. More recently, however, attention has been given to the role of negative relations in equivalence formation (e.g., Saunders & Green, 1992). Specifically, evidence suggests that negative relations between samples and "incorrect" comparisons on matching-to-sample tasks can play an important role in generating the derived relations that emerge in the test performance (e.g., Steele & Hayes, 1991, pp. 546–547). To date, however, derived negative relations have been examined solely within the context of matching-to-sample tests, and thus it remains unclear as to whether negative relations will have any consistent effects on a transfer of functions. The third experiment in the current study addressed this issue.

During Experiment 3, subjects were trained in the four conditional discrimination tasks employed in Experiments 1 and 2. In addition, two other matching-to-sample tasks were introduced in which subjects were trained to select D1 and not ND1 in the presence of C1, and to select D2 and not ND2 in the presence of C2. In accordance with the two previous experiments, one member from each equivalence class (B1 and B2) was then made discriminative for two different patterns of operant responding on a reinforcement schedule. Given this training history, it is predicted that ND1, through its negative and equivalence relations to B1 (i.e., ND1 × C1-A1-B1), should *not* be discriminative for the operant pattern established in the presence of B1. Similarly, ND2, through its negative and equivalence relations to B2 (i.e., ND2 × C2-A2-B2), should *not* be discriminative for the operant pattern trained in the presence of B2. These derived negative relations, and the forced choice between only two operant patterns, make it likely that the discriminative function of B1 will transfer to ND2 and the discriminative function of B2 will transfer to ND1. This effect will be referred to as a transfer of functions through S− control (see Sidman, 1987) and equivalence (or derived S− control).

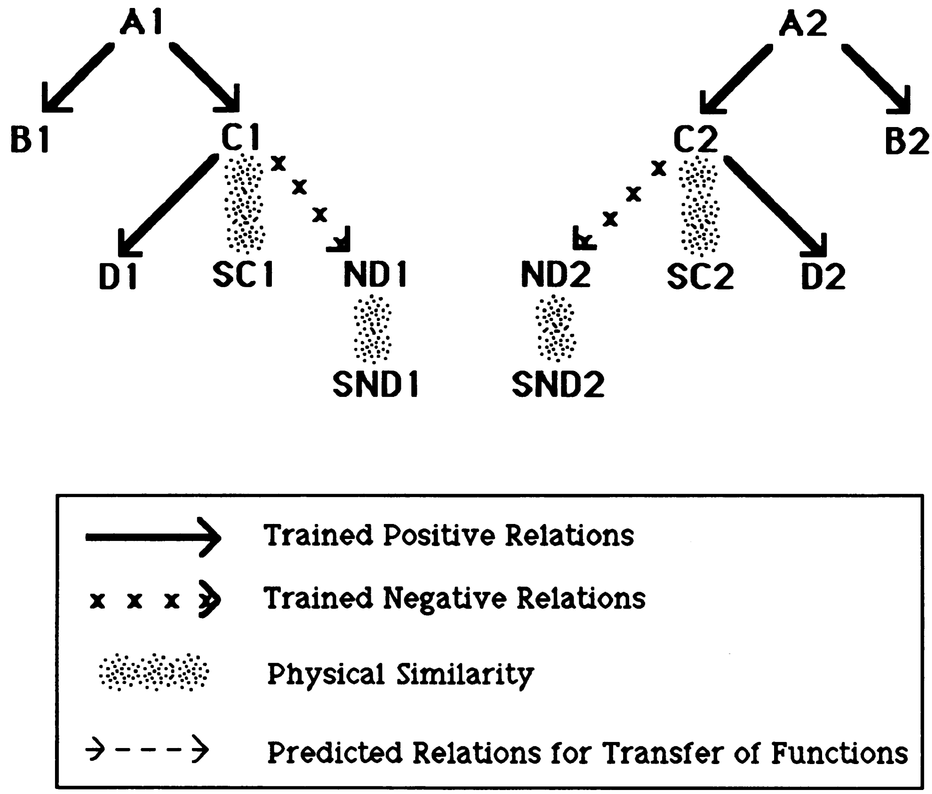
Although Experiment 3 examined one way in which derived S− control may determine schedule performance, the involvement of the nonarbitrary relation of physical similarity may again provide an additional mode of transfer. Experiment 4 examined one way in which this might occur. The study was identical to Experiment 3, except that additional transfer of control test trials were included that permitted an examination of the stimulus functions of two novel stimuli, SND1 and SND2, that were physically similar to ND1 and ND2, respectively. That is, the ND1 and ND2 stimulus functions, derived through S− control and equivalence, were expected to transfer to SND1 and SND2, respectively (i.e., SND1 = high rate, SND2 = low rate). The trained and predicted relations for all four experiments are shown in Figure 1.

The present studies also addressed a number of additional issues. First, we attempted to control for extraneous feedback effects through the use of a stability criterion for performance on the tests of transfer of control. With only one exception (Hayes et al., 1991, Experiment 4), experiments on transfer of control often cycle between training and testing, or provide extensive exposure to the testing tasks, until the predicted performance emerges. This procedure may inadvertently provide feedback about the task. More informally, the subjects may think, "I keep getting the same problems; I must be getting it wrong so I'll have to try something else." To control for this type of feedback, the current studies required that subjects meet a predetermined stability criterion during transfer-of-control testing, in which performances other than those predicted may emerge. Of course, the feedback effect may still occur before subjects have met the stability criterion. However, if predicted performances emerge, as opposed to a number of other acceptable alternatives, this would strongly suggest that the predicted performances are in fact largely derived from the trained relations and not from the feedback provided by typical transfer-of-control procedures.

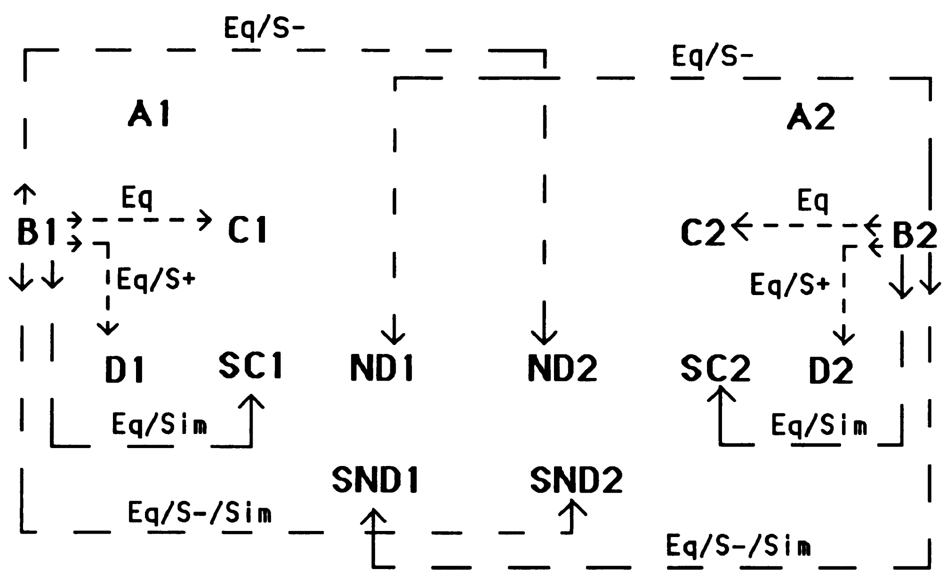
Second, the present studies did *not* involve testing a transfer of functions from samples to directly paired comparisons, thereby circumventing a number of interpretive problems. As an example, consider again the two studies reported by de Rose, McIlvane, Dube, Galpin, and Stoddard (1988) and de Rose, McIlvane, Dube, and Stoddard (1988). Subjects were first trained in the discriminative functions for the A stimuli, and were then trained in the A-B conditional discriminations. It is possible, therefore, that the directly reinforced pairings of the A and B stimuli allowed direct associative processes, such as stimulus compounding, to produce the transfer of functions from A to B (see Hayes et al., 1991). Thus, if the B stimuli were controlling behavior as part of a stimulus compound, the subsequent transfer of functions from the B to D stimuli required only a transfer through symmetry and not equivalence. In the present studies, therefore, all predicted performances required a transfer of functions across the B and C stimuli that are neither seen nor paired with reinforcement together. The relation between B and C stimuli is entirely indirect and is an equivalence relation (Fields, Verhave, & Fath, 1984).

Third, the present studies examined whether a standard equivalence test was required for the predicted transfer of functions to emerge (see Sidman, Kirk, & Willson-Morris, 1985). One recent study (Hayes et al., 1991, Experiment 2) demonstrated a reliable transfer of functions across 4 subjects without first testing for equivalence (1 subject was exposed to a test for symmetry before a transfer of functions was observed). Given the complexity of the predicted relations in the current experiments, a demonstration of these relations without a prior equivalence test would be a further important

Trained and Physical Similarity Relations



Derived Relations for Transfer of Functions



contribution to establishing the range and power of the transfer-of-functions phenomenon. The present studies, therefore, introduced standard equivalence tests only after subjects had reached the stability criterion on the transfer-of-control tests.

GENERAL METHOD

Subjects

Thirty-two students, 16 male and 16 female, enrolled at the University of Ulster at Coleraine, served as subjects. Their ages ranged from 18 to 30 years (mode = 21). All subjects were recruited through faculty notice-board advertisement and personal contacts; none were students of psychology. Subjects were randomly assigned to one of four experiments (i.e., 8 subjects to each experiment).

Apparatus and Materials

Subjects were seated at a table in a small experimental room with an Acorn Computer Limited, British Broadcasting Corporation (BBC), Model B microcomputer with a Cumana (Model CS400) floppy disk drive and a Kaga Denshi (Model KG-12NB-N) computer monitor that displayed green characters on a black background. Stimulus presentation and the recording of responses were controlled by the computer, which was programmed in BBC BASIC.

General Experimental Sequence

There were four phases to each of the four experiments. During Phase 1, subjects were taught a series of conditional discriminations. In Phase 2, two of the stimuli employed during Phase 1 were established as discriminative stimuli. Three types of tests were carried out during Phase 3: (a) The conditional discrimination test determined whether the performances taught during Phase 1 were intact, (b) the discriminative function test determined whether the performances taught during Phase 2 were intact, and (c) the transfer of control test was used to determine whether stimuli that had *not* been explicitly established as discriminative stimuli during Phase 2 had acquired specific discriminative functions. During Phase 4, matching-to-sample test trials were used to determine whether the stimuli employed in the previous three phases had formed two derived stimulus classes.

Matching to Sample

The procedures for controlling and monitoring the matching-to-sample tasks were based on previous experimental work (McIlvane et al., 1987). Conditional discriminations were examined using a matching-to-sample procedure. Stimuli were three-letter nonsense syllables (e.g., CUG, VEK). The sample and two comparison stimuli always differed in at least two letters. For matching-to-sample trials, the sample appeared in the center at the top of the monitor screen, with the comparison stimuli to the left and right, positioned 12.7 cm from the bottom of the screen. Across trials, the left-right positions of the two comparison stimuli were randomly varied. The subject selected a comparison stimulus by typing its constituent characters on the keyboard; as this was done, the characters appeared on the monitor screen, in the bottom left corner. The subject could use the computer keyboard's DELETE key to erase any mistyped letters and could reenter the correct ones. A matching-to-sample trial was completed by pressing the RETURN key on the keyboard. The selected comparison stimulus was defined as either correct or incorrect, depending upon which sample stimulus was present.

Schedule Performance

During schedule performance trials, a single three-letter nonsense syllable appeared in the center of the monitor screen. Subjects were required to press the space bar on the computer keyboard (the auto-repeat function was disabled for the entire study). Depending on which syllable was present, one of two reinforcement schedules was in operation: (a) a recycling conjunctive differential-reinforcement-of-other-behavior, fixed-interval 10-s (DRO FI 10-s) schedule, or (b) a recycling conjunctive fixed-ratio 20, fixed-interval 10-s (FR 20 FI 10-s)

←

Fig. 1. Schematic representation of the trained relations (upper diagram) and predicted derived relations (lower diagram) across the four experiments. "Eq" represents an equivalence relation, "S+" represents a derived positive relation, "S−" represents a derived negative relation, and "Sim" represents a physical similarity relation.

schedule. For both schedules, the first response following the programmed 10-s interval completed the trial and recycled the schedule (i.e., the schedules were not normal conjunctives because the DRO or FR requirements had to be met within the programmed 10-s interval). The recycling conjunctive DRO FI 10-s schedule required that the subject not respond at all (i.e., not press the space bar) during the entire programmed 10-s interval. If this requirement was met, the first response after the interval had elapsed completed the trial and the subject's performance was defined as correct. If the subject made one or more responses during the 10-s interval, the first response after the interval had elapsed completed the trial, and the subject's performance was defined as incorrect. The recycling conjunctive FR 20 FI 10-s schedule required that the subject emit at least 20 responses (i.e., space bar presses) during the programmed 10-s interval. If this requirement was met, the first response after the interval had elapsed completed the trial, and the subject's performance was defined as correct. If the subject failed to emit 20 or more responses during the 10-s interval, the first response after the interval had elapsed completed the trial and the subject's performance was defined as incorrect.

Programmed Consequences

During the first half of Phase 1 and the first half of Phase 2, the correct completion of a matching-to-sample or schedule control trial removed the stimulus display and produced "correct" in the center of the screen; on about one third of these "correct" presentations, the program also printed a message in the lower half of the screen indicating that a coin had been earned (i.e., "two pence"). The incorrect completion of a matching-to-sample or schedule control trial removed the stimulus display and produced "wrong" in the center of the screen. The written feedback remained on the screen for 2 s before being erased, and an intertrial interval of 1.5 s preceded the next trial. During the latter half of Phase 1 and the latter half of Phase 2, feedback followed only about 50% of completed trials (i.e., intermittent feedback). During Phases 3 and 4, no feedback occurred on any trial. On those trials in which there was no feedback, the program merely advanced to the intertrial interval. Subjects could earn about £10 to £20 in the course of their participation. No information was given about accumulated earnings until after the subjects had completed the entire experiment.

Typing Errors

Because subjects typed their comparison selections during the matching-to-sample task, typing errors (i.e., letters incorrect, repeated, or out of order) could occur. The computer screened every comparison stimulus entered by the subject for such typing errors. If any two of the three letters typed appeared in the correct comparison stimulus, "typing error" appeared in the center of the monitor screen and the same sample and comparisons were presented again. A subject could correct the typing error by reentering his or her selection. The appropriate programmed consequence followed this correction procedure.

General Procedure

All subjects were trained and tested individually in one or more sessions lasting approximately 45 to 120 min each. The number of sessions required to complete the entire experiment varied from one to 14 across subjects. Only 2 subjects per day were booked for experimentation (one in the morning and the other in the afternoon) so that subjects never met each other in the general vicinity of the experimental psychology building. Furthermore, all subjects were asked not to inform anyone about their participation in the study until after they had been paid (all money earned was paid 1 month after the entire study had been completed).

At the beginning, the experimenter familiarized the subject with the keyboard, including the RETURN and DELETE keys. Those few subjects who were unfamiliar with computer keyboards were encouraged to play a computer game to practice appropriate input procedures. At the start of the first session, each subject was presented with the following instructions on the monitor:

> Now that you are familiar with the basic input operations, you will start the experiment. In the first stage of the study you will learn tasks involving nonsense syllables ("ZOM," "KAQ," etc.). On each trial you will see two choice items displayed side-by-side. Soon, the computer will teach you how to make choices between the two items, based on a third item that is displayed above them.

> ZOM
>
> KAQ QAS
>
> For example, here your choices are either "KAQ" or "QAS." (You do not know which choice is correct yet, of course.) In other words, when "ZOM" is displayed, you choose one item from the two below. You choose by typing the item on the keyboard and then pressing the RETURN key. Try entering one of the choice items now and see what happens. You can have a number of goes [sic] before we move on.

Subjects were exposed to this single task for four trials (choosing KAQ was always reinforced) to familiarize them with the matching-to-sample procedure. None of the three stimuli used in this pretraining task were employed in the actual experiments. After the four pretraining trials, the monitor screen cleared and the following instructions appeared:

> You might have noticed that the program checks for typing errors. If you make a response that is recognized as a typing error, the choices will be re-presented, and you must enter the characters correctly. There is no other penalty for a typing error.
>
> A later stage of the experiment involves pressing the space bar at the bottom of the keyboard. All you have to do is figure out when to either: (1) keep pressing the space bar as fast as you can, or (2) NOT press the space bar for a long period of time before pressing just once. You do NOT have to press the RETURN key during space-bar pressing tasks.
>
> Every time you finish a trial correctly you earn two pence. In order to participate fully in the study (and earn the full amount of money), you must master these basic tasks.
>
> Please note that sometimes the computer will tell you at the end of a trial whether you were "Correct" or "Wrong." At other times, however, no feedback will be provided at the end of a trial. This is part of the study.
>
> If you have any questions, please ask them now. The experimenter is not allowed to answer questions once the experiment has started.
>
> Type "BEGIN" when you are ready to start the experiment.

If a subject reported being unsure of the tasks involved, exposure to the instructions and pretraining trials was repeated until the subject indicated readiness to commence the experiment.

Once the session had started, there was no further contact between subject and experimenter. However, additional instructions were presented on the monitor during the course of the experiment. These will be outlined below in the procedure section of Experiment 1. Sessions ended when subjects had completed one, two, three, or sometimes four of the phases, depending on how quickly they proceeded with the task. Sessions were resumed either later the same day or within the next 1 or 2 days, until the experiment was completed.

EXPERIMENTS 1 AND 2: DERIVED S+ RELATIONS

Experiment 1

Procedure

Training. A pool of six nonsense syllables (CUG, ZID, DAX, YIM, VEK, BEH) were used to construct four different stimulus training sets. Each set had two three-member classes and was made by randomly assigning the nonsense syllables to roles as either sample or comparison stimuli. Pairs of subjects were trained with one of the four sets (i.e., 2 subjects to each stimulus set). This was done to rule out stimulus similarity, stimulus attractiveness, or other nonarbitrary aspects of the stimuli as the source of any transfer of function obtained.

During Phase 1, subjects were trained in a set of conditional discriminations using a matching-to-sample procedure. On each trial, the sample (A1 or A2) was presented with the two comparison stimuli (B1-B2, C1-C2). When A1 was the sample, B1 and C1 were correct and B2 and C2 were incorrect. When A2 was the sample, B2 and C2 were correct and B1 and C1 were incorrect. Thus, subjects were trained on four tasks (A1-B1, A2-B2, A1-C1, A2-C2). These four tasks were presented in a quasi-random order for a total 160 trials (each task occurring twice every eight trials). Intermittent feedback was introduced for the final 80 trials. The mastery criterion for successful completion of Phase 1 was 39 correct responses across the final 40 trials. If this criterion was not met, the subject was exposed to a further 40 trials with intermittent feedback still in operation. This 40 trial cycle was repeated until the subject met the mastery criterion.

After completion of the conditional discrimination training (Phase 1), subjects were exposed to the discriminative function training (Phase 2). The following instructions were presented on the monitor screen before training commenced:

> The next stage of the experiment involves the space-bar pressing tasks. Remember, all you have to do is figure out when to either: (1) keep pressing the space bar as fast as you can, or (2) NOT press the space bar for a long period of time before pressing just once.
>
> Type "BEGIN" when you are ready to start.

The B1-B2 stimuli, which had served as one of the two sets of comparison stimuli during conditional discriminations, were presented separately on individual trials. When B1 was present, the subject was exposed to the recycling conjunctive DRO FI 10-s schedule, and when B2 was present the subject was exposed to the recycling conjunctive FR 20 FI 10-s schedule. Thus, subjects were trained to emit a low-rate pattern of responding in the presence of B1 and a high-rate pattern of responding in the presence of B2. These two schedule control tasks were presented in a quasi-random order for a total of 50 trials (each task occurring five times every 10 trials). Intermittent feedback was introduced for the final 25 trials. The mastery criterion for completing Phase 2 was nine correct response patterns across the final 10 trials. If this criterion was not met, the subject was exposed to a further 10 trials with intermittent feedback still in operation. This 10-trial cycle was repeated until the subject met the mastery criterion.

Testing. After completion of the discriminative function training (Phase 2), subjects were exposed to three types of tests in the form of 40 schedule performance trials and 40 matching-to-sample trials (Phase 3, Stages 1 and 2). Schedule performance and matching-to-sample trials were presented alternately throughout Phase 3. All trials (a total of 80) ended without any feedback. The following instructions appeared on the monitor screen before the testing trials commenced:

> During the next part of the experiment you are going to be exposed to the nonsense syllable choice tasks and the space-bar pressing tasks on alternate trials. In other words, after every space-bar pressing trial you will be presented with a nonsense syllable choice trial.
>
> Type "BEGIN" when you are ready to start.

Testing always started with a schedule performance trial. The first 10 schedule performance trials constituted the discriminative function test (Stage 1). This consisted of the two tasks that had been directly trained during Phase 2. The tasks were presented in a quasi-random order, each occurring five times. The remaining schedule performance trials constituted the transfer-of-control test (Stage 2). That is, the C1-C2 stimuli were presented separately on 30 individual trials in a quasi-random order (each occurring 15 times). This test examined the transfer of discriminative control from the B1-B2 stimuli to the C1-C2 stimuli through symmetry (e.g., C1-A1) and transitivity (e.g., C1-A1-B1). The 40 matching-to-sample trials, which alternated with the schedule performance trials, constituted the conditional discrimination test. This consisted of the four tasks that were directly trained during Phase 1. The four tasks were presented in a quasi-random order, each task occurring once across every four matching-to-sample trials. The basic training and testing sequence for Experiment 1 is presented in Table 1.

Testing stability criteria. There were three stability criteria, one criterion for each type of test. If at the end of Phase 3 a subject failed to meet any of these criteria, he or she was returned to the beginning of one of the three phases and proceeded once again, in sequence, through the remainder of the experiment (the rationale for deciding which phase a subject was returned to is outlined below). This procedure was repeated until all three criteria were met. In order to help prevent these recursive training and testing procedures from serving as discriminative stimuli for alternative response strategies, subjects were not told that they had "failed" or were repeating previous phases of the experiment. Instead, a message was presented on the monitor screen before reexposure to any of the phases. The message simply stated which type of tasks were to follow (e.g., before returning to Phase 1: "In the next stage of the experiment you will be exposed to nonsense syllable choice tasks on their own").

The conditional discrimination stability criterion was a minimum of 90% correct responses across all of the conditional discrimination test trials. If subjects failed to meet this criterion, it was assumed that the conditional discriminations were not fully established. Subjects were returned to the beginning of

Table 1

The basic training and testing sequences for Experiments 1 and 2. Correct responses on matching-to-sample tasks are underlined. Correct performances on schedule trials are indicated by low rate and high rate.

Phase 1		
Train:	A1 B1 B2	A2 B2 B1
	A1 C1 C2	A2 C2 B2
Phase 2		
Train	B1 = low rate	B2 = high rate
Phase 3		
Test		
Schedule performance trials alternate with Phase 1 trials		
Stage 1	B1 = low rate	B2 = high rate
Stage 2		
Experiment 1		
Equivalence:	C1 = low rate	C2 = high rate
Experiment 2		
Equivalence and similarity:	SC1 = low rate	SC2 = high rate
Stage 3		
Experiment 2		
Equivalence:	C1 = low rate	C2 = high rate
Phase 4		
Test		
Experiments 1 and 2		
Symmetry:	B1 A1 A2	B2 A2 A1
	C1 A1 A2	C2 A2 A1
Equivalence:	B1 C1 C2	B2 C2 C1
	C1 B1 B2	C2 B2 B1
Experiment 2 only		
Similarity:	SC1 C1 C2	SC2 C2 C1
Symmetry and similarity:	SC1 A1 A2	SC2 A2 A1
Equivalence and similarity:	SC1 B1 B2	SC2 B2 B1

Phase 1 without regard to performance on either the discriminative function test or the transfer-of-control test.

The stability criterion for the discriminative function test (Stage 1) was nine correct schedule performances across the 10 discriminative function test trials. If subjects failed to meet this criterion, it was assumed that the discriminative functions were not fully established. Subjects were returned to the beginning of Phase 2 without regard to performance on the transfer-of-control test.

The stability criterion for the transfer of control test (Stage 2) allowed for stable performances other than those predicted on the basis of a transfer of control through symmetry and transitivity. Instead, the stability criterion required that subjects emit the *same* pattern of responding in the presence of the *same* nonsense syllable across *all* of the transfer-of-control test trials. This permitted three types of stable performance *not* predicted by the transfer of control: (a) a low-rate performance in the presence of both the C1 and C2 stimuli; (b) a high-rate performance in the presence of both the C1 and C2 stimuli; and (c) a high-rate performance in the presence of the C1 stimulus and a low-rate performance in the presence of the C2 stimulus. If a subject failed to meet the stability criterion, it was assumed that the response patterns emitted during the transfer of control test did not reflect reliably established behavioral relations. Therefore, subjects were returned to the beginning of Phase 3.

During a pilot study, it was noticed that "genuine" mistakes could occur during a low-rate performance (e.g., accidentally hitting the space bar, or pressing just before the end of the fixed interval). To allow for these mistakes, during schedule performance test trials a recycling conjunctive (conjoint DRO/FR < 3) FI 10-s schedule was employed. That is, during Phase 3 a response pattern was considered low rate even if one or two responses occurred during the fixed interval. The definition of a high-rate performance (i.e., 20 or more responses during the fixed interval) remained unchanged.

Table 2 presents the obtained training and test sequences for each subject across the first three phases of the experiment. Subject 1, for example, required 200 trials of conditional discrimination training (Phase 1), followed by 50 trials of discriminative function training (Phase 2). During the first exposure to the three test stages (Phase 3), this subject failed to meet the discriminative function test stability criterion and was returned to the beginning of Phase 2, where a further 50 trials were required. Subject 1 was then exposed to Phase 3 for a second time and met the stability criteria.

Equivalence testing. When subjects had met all three of the stability criteria for completion of Phase 3, they were exposed to an equivalence test (Phase 4). This test was used to determine whether two equivalence classes (A1, B1, C1 and A2, B2, C2) had formed. The equivalence test consisted of eight matching-to-sample tasks. Four of the tasks tested for symmetry, and the other four tasks tested for combined symmetry and transitivity. For the symmetry tasks, the B and C stimuli served as samples and the A stimuli served as comparisons. For the combined symmetry and transitivity tasks, the B and C stimuli served as both samples and comparisons. These eight tasks were presented in a quasi-random order (each task occurring once every eight trials) for a total of 64 trials. There was no stability criterion, and subjects were exposed to the equivalence test only once.

EXPERIMENT 2

Procedure

All procedural aspects of Experiment 2 were identical to Experiment 1, with a number of important exceptions (see Table 1). An additional test (Stage 2) was inserted into Phase 3 of the experiment. During this test, subjects were exposed to 30 schedule performance test trials that examined a transfer of control through equivalence to physically similar stimuli. One of two nonsense syllables (i.e., SC1 and SC2) was presented separately on 30 individual trials in a quasi-random order (each occurring 15 times). These syllables were physically similar to C1 and C2 stimuli, in that their first and last letters were the same. That is, when C1 was DAX and C2 was BEH, then SC1 was DUX and SC2 was BIH; when C1 was BEH and C2 was DAX, then SC1 was BIH and SC2 was DUX. This test examined the transfer of discriminative control from the B1-B2 stimuli to the SC1-SC2 stimuli via equivalence (e.g., B1-C1) and physical similarity (e.g., C1-SC1). Upon completing Stage 2, subjects were exposed to the test of transfer of control through equivalence, which was identical to that in Experiment 1. It should also be noted that the inclusion of the additional 30 schedule performance test trials during Stage 2 meant that the number of alternating conditional discrimination test trials presented during Phase 3 was 70 instead of the 40 presented in Experiment 1.

The three stability criteria employed during Phase 3 of Experiment 1 were also used for Phase 3 of Experiment 2. However, the inclusion of the additional test examining a transfer of control through equivalence and physical similarity meant two important changes from Experiment 1. First, a subject had to produce a consistent pattern in the presence of four, instead of two, different nonsense syllables (i.e., SC1, SC2, C1, and C2) across all transfer-of-control test trials (Stages 2 and 3). If a subject failed to meet the transfer-of-control stability criterion during either Stages 2 or 3, this is indicated in the obtained training and test sequences presented in Table 2. Second, because there were now four types of schedule performance trials presented during Phase 3, this permitted 15 types of stable performance *not* predicted by the transfer of control through equivalence and physical similarity.

The equivalence test (Phase 4) employed the same eight tasks used in Experiment 1. However, an additional six tasks were included in the test. These test trials were used to determine whether SC1 and SC2 were related to the C stimuli through physical similarity, to the A stimuli through physical similarity and symmetry, and to the B stimuli through physical similarity and equivalence. For these tasks, SC1 and SC2 stimuli served as samples and the A, B, and C stimuli served as comparisons. These six additional tasks and the eight standard equivalence tasks were presented concurrently in a quasi-random order (each task occurring once every 14 trials) for a total of 112 trials.

Table 2

Obtained number of trials and training and test sequences for subjects across Phases 1, 2, and 3 of the four experiments.

Experiment 1				Experiment 2				Experiment 3				Experiment 4			
Subject	1	2	3	Subject	1	2	3	Subject	1	2	3	Subject	1	2	3
S1	200	50	Fail/Stage 1	S9	160	50	Fail/Stage 2	S17	240	160	Fail/Stages	S25	240	90	Fail/Stages
		50	Pass				Pass				2 and 3				2 and 3
S2	160	80	Pass	S10	200	70	Fail/Stages				Fail/Stage 3				Fail/Stage 4
S3	240	50	Fail/Stage 2				2 and 3				Pass				Pass
			Pass				Pass				Fail/Stage 2(2)	S26	240	80	Pass
			Fail/Stage 2(2)[a]	S11	240	70	Fail/Stage 1	S18	300	80	Pass	S27	240	60	Fail/Stage 1
S4	280	60	Pass			50	Fail/Stage 1				Pass			50	Fail/cond. dis.
			Pass			50	Fail/Stages	S19	240	50	Fail/Stage 1		240	50	Fail/Stages
S5	160	50	Fail/Stage 1				2 and 3	S20	300	120	Fail/Stages				2, 3, and 4
S6	320	120	Fail/cond. dis.[b]				Fail/Stage 2(2)			50	2 and 3				Fail/Stage 3
		50	Fail/Stage 2(2)				Pass				Fail/cond. dis.				Pass
	160	50	Pass	S12	160	50	Pass				Fail/Stage 2	S28	240	50	Pass
			Pass	S13	240	60	Fail/cond. dis.		240	50	Pass	S29	360	50	Fail/cond. dis.
S7	160	50	Pass		160	60	Pass				Pass		240	60	Pass
S8	200	50		S14	240	110	Fail/Stage 2(2)	S21	300	60					
							Pass	S22	240	60	Fail/cond. dis.				
				S15	240	70	Fail/Stage 3		240	60	Pass	S30	240	110	Fail/Stage 1
							Pass	S23	240	50	Pass			50	Fail/cond. dis.
				S16	160	50	Fail/Stage 1	S24	360	60	Fail/Stage 1		240	60	Fail/Stages
						50	Pass			50	Fail/Stage 1				2, 3, and 4
										50	Fail/Stages				Fail/Stage 3
											2 and 3				Fail/Stage 1
											Fail/cond. dis.			50	Fail/cond. dis.
									240	50	Fail/Stage 2		240	60	Pass
											Pass	S31	300	50	Fail/Stage 1
														50	Fail/Stages
															2 and 3(2)
															Fail/cond. dis.
													240	50	Pass
												S32	300	60	Fail/Stages
															2, 3, and 4(5)
															Pass

[a] Numbers in parentheses record the number of times the subject repeatedly failed to achieve the stability criterion for the indicated stage or stages. If a subject failed a stage or stages only once, the parentheses are omitted.

[b] cond. dis. refers to the conditional discrimination test trials that alternated with the schedule control trials throughout Phase 3.

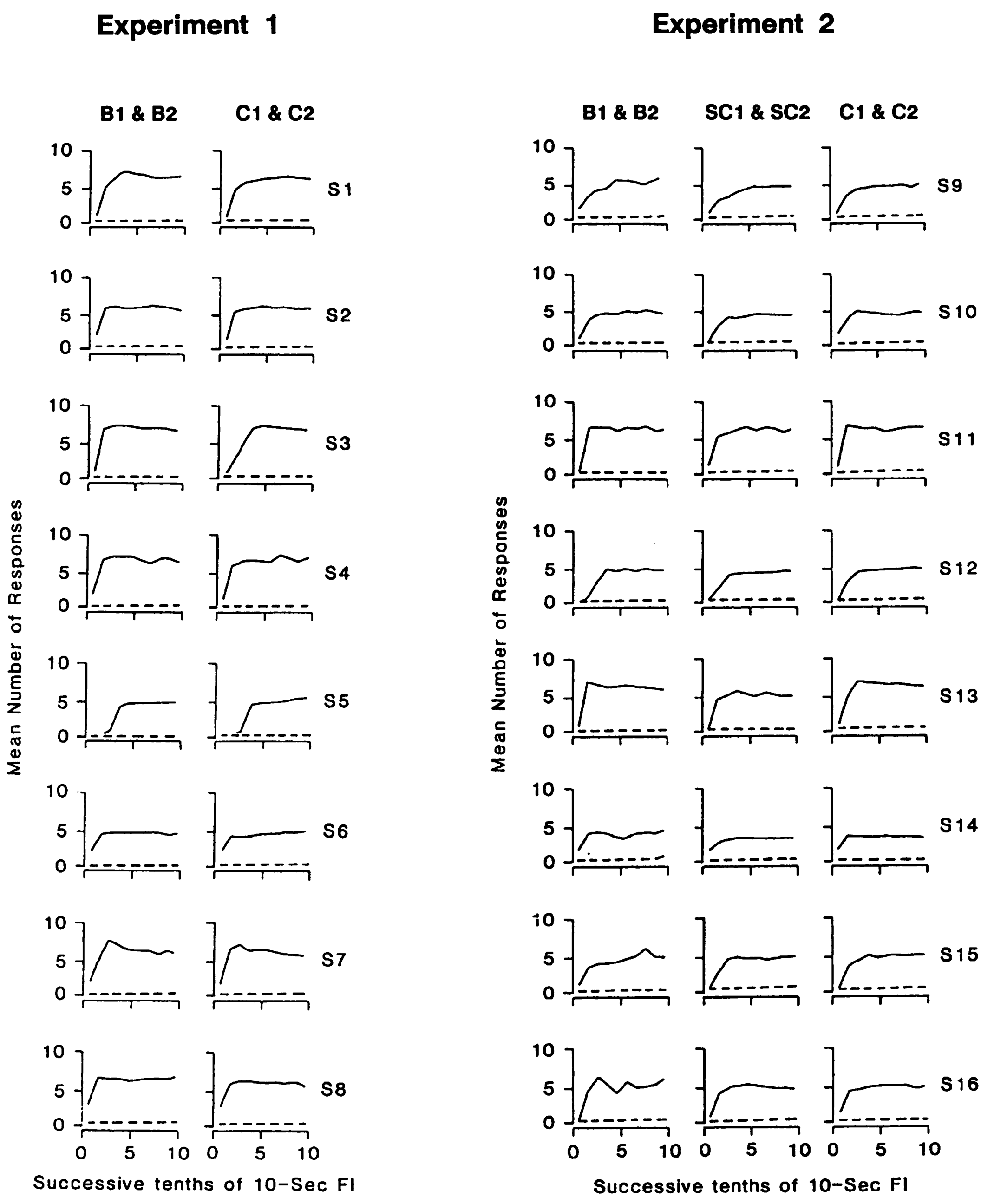


Fig. 2. The mean number of responses in successive 10ths of the 10-s fixed interval for subjects in Experiments 1 and 2 in the presence of B1, C1, SC1 (dashed lines) and B2, C2, SC2 (solid lines).

Results

The discriminative function and transfer-of-control data are from each subject's final exposure to Phase 3 in Experiments 1 and 2. In those cases in which a subject was exposed only once to Phase 3, the results are from that single exposure (see Figure 2).

Across discriminative function test trials, all subjects in both experiments produced low-rate average local response rate patterns in the presence of B1 and high-rate patterns in the presence of B2. During test trials examining a transfer of functions through equivalence, all subjects from Experiments 1 and 2 emitted low-rate patterns in the presence of C1 and high-rate patterns in the presence of C2. During test trials examining a transfer of control through equivalence and physical similarity (Experiment 2), all subjects produced low-rate patterns in the presence of SC1 and high-rate patterns in the presence of SC2.

When subjects were exposed to the standard equivalence tests (Phase 4), they all responded in accordance with the predicted equivalence and physical similarity relations in both experiments (Table 3). Of the 64 trials examining symmetry and equivalence (Experiments 1 and 2), correct responses varied between 60 and 64 across subjects. Of the 48 trials examining physical similarity and physical similarity through symmetry and through equivalence (Experiment 2), subjects emitted between 44 and 48 correct responses.

EXPERIMENTS 3 AND 4: DERIVED S− RELATIONS

EXPERIMENT 3

Procedure

The general training and testing sequence for Experiment 3 was similar to Experiment 2, with some important differences (see Table 4). Four additional nonsense syllables were used in this experiment (MAU, PAF, ROG, WOB). The standard equivalence training procedure normally involves presenting one sample stimulus and two or more comparison stimuli. To control for a history of reinforcement for selecting particular stimuli, the incorrect comparison stimuli were correct in the presence of other samples. This training format was employed in Experiments 1 and 2. Experiment 3 departed from this standard format in order to examine the role of derived S− control relations in the transfer of stimulus functions. It is important to understand that the transfer-of-control test (i.e., presentation of a single stimulus on each trial) does not involve selecting comparison stimuli in the presence of samples. This form of test thereby circumvents any interpretative problems arising from a reinforcement history for selecting particular stimuli. In other words, if the S− control is nonderived, then the two S− stimuli

Table 3

Equivalence tests across the four experiments.

Experiment 1		Experiment 2			Experiment 3				Experiment 4				
Subject	Equiv	Subject	Equiv	Equiv/Sim	Subject	Equiv	S+	S−	Subject	Equiv	S+	S−	S−/Sim
S1	64	S9	60	47	S17	64	48	48	S25	62	46	48	48
S2	60	S10	64	46	S18	64	48	46	S26	64	47	48	48
S3	64	S11	64	44	S19	62	48	47	S27	63	47	46	47
S4	62	S12	60	46	S20	63	45	44	S28	61	48	47	45
S5	64	S13	64	48	S21	64	47	48	S29	64	46	48	46
S6	64	S14	61	47	S22	64	48	48	S30	64	48	44	48
S7	61	S15	63	48	S23	62	47	47	S31	64	48	46	48
S8	64	S16	64	48	S24	64	48	47	S32	63	46	48	47
M	62.87	*M*	62.5	46.75	*M*	63.37	47.37	46.88	*M*	63.12	47.00	46.87	46.87

Table 4

The basic training and testing sequences for Experiments 3 and 4. Correct responses on matching-to-sample tasks are underlined. Correct performances on schedule trials are indicated by low rate and high rate.

Phase 1		
Train:	Identical to Experiments 1 and 2 except for:	
	C1 $\underline{\text{D1}}$ ND1	C2 $\underline{\text{D2}}$ ND2
Phase 2		
Train:	Identical to Experiments 1 and 2	
Phase 3		
Test		
Schedule performance trials alternate with Phase 1 trials		
Stage 1	Identical to Experiments 1 and 2	
Stage 2		
Experiment 3		
Derived S− control through equivalence:	ND1 = high rate	ND2 = low rate
Experiment 4		
Derived S− control through equivalence and similarity:	SND1 = high rate	SND2 = low rate
Stage 3		
Experiment 3		
Derived S+ control through equivalence:	D1 = low rate	D2 = high rate
Experiment 4		
Derived S− control through equivalence:	ND1 = high rate	ND2 = low rate
Stage 4		
Experiment 4		
Derived S+ control through equivalence:	D1 = low rate	D2 = high rate
Phase 4		
Test		
Experiments 3 and 4		
Symmetry and equivalence:	Identical to Experiments 1 and 2	
S+ control:	D1 $\underline{\text{C1}}$ C2	D2 $\underline{\text{C2}}$ C1
Derived S+ control through symmetry:	D1 $\underline{\text{A1}}$ A2	D2 $\underline{\text{A2}}$ A1
Derived S+ control through equivalence:	D1 $\underline{\text{B1}}$ B2	D2 $\underline{\text{B2}}$ B1
S− control:	ND1 C1 $\underline{\text{C2}}$	ND2 C2 $\underline{\text{C1}}$
Derived S− control through symmetry:	ND1 A1 $\underline{\text{A2}}$	ND2 A2 $\underline{\text{A1}}$
Derived S− control through equivalence:	ND1 B1 $\underline{\text{B2}}$	ND2 B2 $\underline{\text{B1}}$
Experiment 4 only		
S− control through similarity:	SND1 C1 $\underline{\text{C2}}$	SND2 C2 $\underline{\text{C1}}$
Derived S− control through symmetry and similarity:	SND1 A1 $\underline{\text{A2}}$	SND2 A2 $\underline{\text{A1}}$
Derived S− control through equivalence and similarity:	SND1 B1 $\underline{\text{B2}}$	SND2 B2 $\underline{\text{B1}}$

should possess the same discriminative functions (i.e., from the subject's perspective, "these two nonsense syllables were never correct, therefore they must go together and mean do the same thing"). The present experimental prediction, however, is that the two S− stimuli will possess different discriminative functions. It should also be noted that standard equivalence tasks were used during Phase 4 (see below) to examine any unexpected behavioral effects generated by the nonstandard conditional discrimination training employed in this experiment.

Phase 1. The four additional nonsense syllables employed in this experiment were used to form two new matching-to-sample tasks. For these tasks C1 and C2 stimuli served as samples, with ND1 and ND2 presented as S− comparisons and D1 and D2 presented as S+ comparisons. These two tasks and the four original matching-to-sample tasks (from the previous experiments) were presented in a quasi-random order for a total of 240 trials (each task occurring twice every 12 trials). Intermittent feedback was introduced for the final 120 trials. The mastery criterion for successful completion of Phase 1 was 58 correct responses across the final 60 trials. If this criterion was not met, the subject was exposed to a further 60 trials with intermittent feedback still in operation. This 60-trial cycle was repeated until the subject met the mastery criterion.

Phase 2. This schedule-performance training phase was identical to previous experiments.

Phase 3. The conditional discrimination test was similar to previous experiments, except that there were now six tasks (from Phase 1) instead of four. All six tasks alternated with the schedule performance test trials throughout Phase 3. Stage 1 employed the same schedule performance tasks as the previous experiments. During Stage 2, subjects were exposed to a test of transfer of control through derived S− relations. One of two nonsense syllables (ND1 and ND2) was presented separately on 30 individual trials in a quasi-random order (each occurring 15 times). This test examined the transfer of discriminative control from the B1-B2 stimuli to the ND2-ND1 stimuli through derived S− relations (e.g., B1-C1 × ND1/forced choice context/B2-ND1). During Stage 3 of Phase 3, subjects were exposed to a test of transfer of control through derived S+ relations. One of two nonsense syllables (D1 and D2) was presented separately on 30 individual trials in a quasi-random order (each occurring 15 times). This test examined the transfer of discriminative control from the B1-B2 stimuli to the D1-D2 stimuli through S+ control and equivalence relations (e.g., B1-A1-C1-D1). The stability criteria for Experiment 3 were identical to Experiment 2. The obtained training and test sequences for each subject across Phases 1, 2, and 3 of this experiment are presented in Table 2.

Phase 4. The equivalence test employed the same eight tasks used in Experiment 1. However, an additional 12 tasks were also included in the test. For six of these tasks, the D stimuli served as samples and the A, B, and C stimuli served as comparisons. These tasks were used to determine whether D1 and D2 were related to the C stimuli through S+ control, to the A stimuli through S+ control and symmetry, and to the B stimuli through S+ control and equivalence. For the remaining six tasks, the negative D stimuli served as samples and the A, B, and C stimuli served as comparisons. These six tasks were used to determine whether ND1 and ND2 were related to the C stimuli through S− control, to the A stimuli through S− control and symmetry, and to the B stimuli through S− control and equivalence. The additional 12 tasks and the eight original equivalence tasks (from Experiment 1) were presented concurrently in a quasi-random order (each task occurring once every 20 trials) for a total of 160 trials.

Experiment 4

Procedure

All procedural aspects of Experiment 4 were identical to Experiment 3, with the following exceptions (see Table 4). An additional test (Stage 2) was inserted into Phase 3 of the experiment. During this test, subjects were exposed to 30 schedule performance test trials that examined a transfer of control through derived S− relations to physically similar stimuli. One of two nonsense syllables (SND1 and SND2) was presented separately on 30 individual trials in a quasi-random order (each occurring 15 times). These syllables were physically similar to ND1 and ND2 stimuli, in that their first and last letters were the same. That is, when ND1 was WOB and ND2 was MAU, SND1 was WIB and SND2 was MEU; when ND1 was MAU and ND2 was WOB, SND1 was MEU and SND2 was WIB. This test examined the transfer of discriminative control from the B1-B2 stimuli to the SND2-SND1 stimuli through derived S− relations (e.g., B1-C1 × ND1/forced choice context/B2-ND1) and physical similarity (ND1-SND1). Upon completing Stage 2, subjects were exposed to the tests of transfer of control through derived S− relations (Stage 3) and the transfer of control through derived S+ relations (Stage 4), which were both identical to those of Experiment 3. It should also be noted that inclusion of the additional 30 schedule performance test trials during Stage 2 meant that the number of alternating conditional discrimination test trials presented during Phase 3 was 100 instead of the 70 presented in Experiment 3.

The three stability criteria employed during Phase 3 of Experiment 3 were also used for Phase 3 of Experiment 4. However, the inclusion of the additional test examining a transfer of control through derived S− relations and physical similarity meant two important changes from Experiment 3. First, a subject had to produce a consistent pattern in the presence of six, instead of four, different nonsense syllables (i.e., SND1, SND2, ND1, ND2, D1, and D2) across all transfer-of-control test trials (Stages 2, 3, and 4). If a subject failed to meet the transfer-of-control stability criterion during either Stages 2, 3, or 4, this is indicated in the obtained training and test sequences presented in Table 2. Second, because there were now six types of schedule performance trials presented during Phase 3, 63 types of stable performance *not* predicted by a transfer of control through S− control, equivalence, and physical similarity were possible.

The equivalence test (Phase 4) employed the same 20 tasks used in Experiment 3. However, an additional six tasks were included in the test. These test trials were used to determine whether SND1 and SND2 were related (a) through physical similarity and S− control to the C stimuli; (b) through physical similarity, S− control, and symmetry to the A stimuli; and (c) through physical similarity, S− control, and equivalence to the B stimuli. For these tasks, SND1 and SND2 stimuli served as samples and the A, B, and C stimuli served as comparisons. These six additional tasks and the other 20 equivalence tasks (from Experiment 3) were presented concurrently in a quasi-random order (each task occurring once every 26 trials) for a total of 208 trials.

Results

The test procedures from Experiments 3 and 4 that replicated test procedures from Experiments 1 and 2 produced performances very similar to those observed in the two previous studies. The following, therefore, will focus only on those data that extend the current findings.

The discriminative function and transfer-of-control data for Experiments 3 and 4 are from each subject's final exposure to Phase 3, or from a subject's single exposure when he or she passed the first time (Figure 3). Across test trials examining a transfer of control through S+ relations and equivalence (Experiments 3 and 4), all subjects produced low-rate patterns in the presence of D1 and high-rate patterns in the presence of D2. For test trials examining the transfer of control through S− relations and equivalence (Experiments 3 and 4), all subjects emitted low-rate patterns in the presence of ND2 and high-rate patterns in the presence of ND1. Test trials examining the transfer of control through S− relations, physical similarity, and equivalence (Experiment 4) produced low-rate patterns in the presence of SND2 and high-rate patterns in the presence of SND1.

When subjects were exposed to the standard equivalence tests (Phase 4), they all responded in accordance with the predicted equivalence, physical similarity, derived S+, and derived S− relations across both experiments (Table 3). Across the 48 trials examining S+ control and derived S+ control through symmetry and through equivalence (Experiments 3 and 4), subjects produced between 45 and 48 appropriate responses. Of the 48 trials examining S− control and derived S− control through symmetry and through equivalence (Experiments 3 and 4), subjects emitted between 44 and 48 appropriate responses. Across the 48 trials examining S− control through physical similarity, derived S− control through physical similarity and symmetry, and through physical similarity and equivalence (Experiment 4), subjects produced between 45 and 48 appropriate responses.

GENERAL DISCUSSION

These four studies show that when a given stimulus becomes discriminative for a particular performance on a complex, time-based schedule of reinforcement, the discriminative function of this stimulus may transfer through a range of derived stimulus relations to other stimuli. In Experiments 1 and 2, stimulus functions were shown to transfer through equivalence relations, and during Experiment 2, a transfer of functions through equivalence and physical similarity was observed for all subjects. During Experiments 3 and 4, subjects demonstrated a transfer of control through equivalence and derived S+ and S− relations, and in Experiment 4, a transfer of functions through physical similarity, S− control, and equivalence was also shown. Finally, responding during matching-to-sample tests corresponded perfectly with the derived performances shown across the transfer-of-control tests.

A Reliable Transfer of Functions

In accordance with previous findings (e.g., Green, Sigurdardottir, & Saunders, 1991; Wulfert & Hayes, 1988), the predicted transfer of functions often emerged after more than

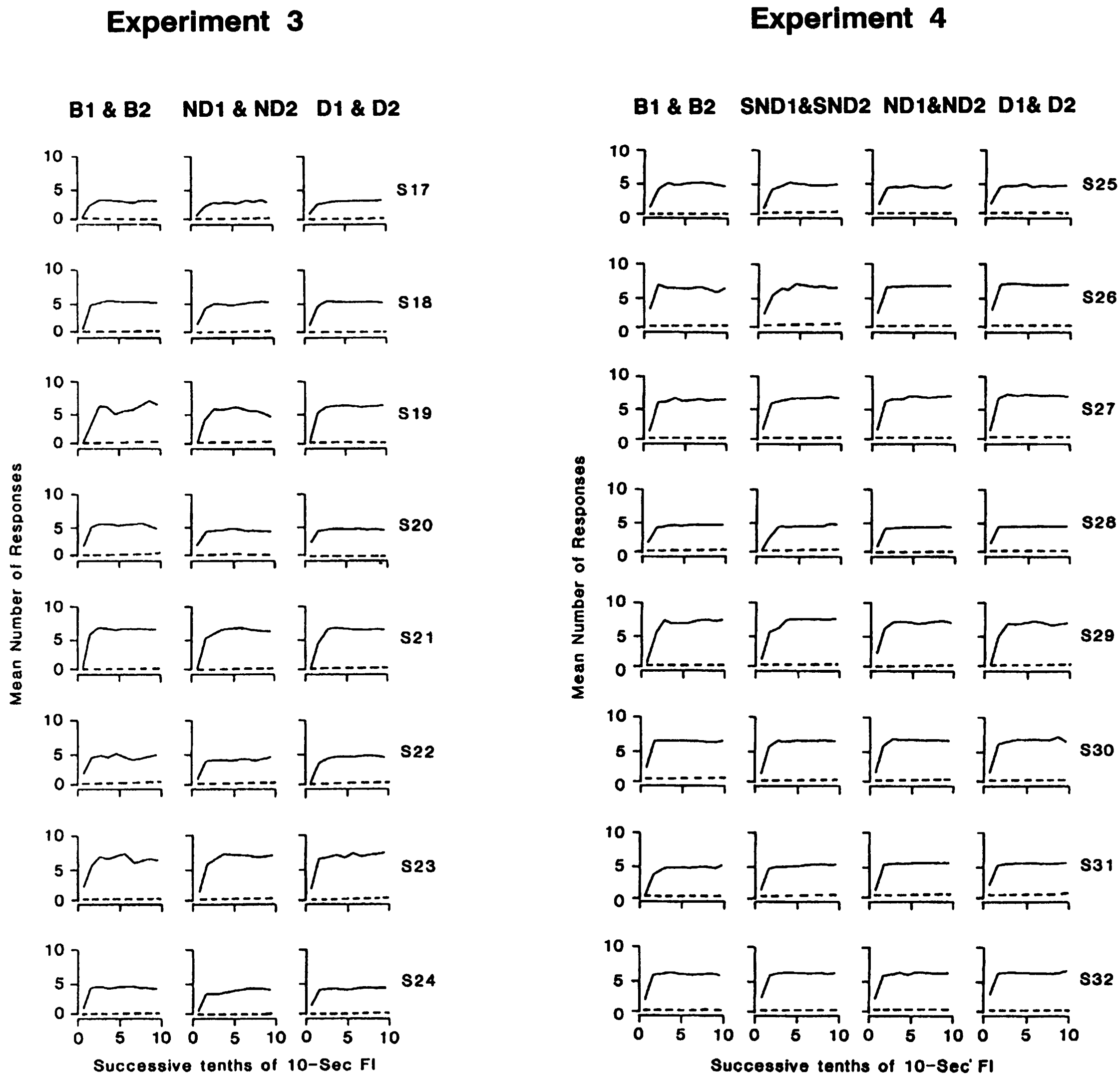


Fig. 3. The mean number of responses in successive 10ths of the 10-s fixed interval for subjects in Experiments 3 and 4 in the presence of B1, D1, ND2, SND2 (dashed lines) and B2, D2, ND1, SND1 (solid lines).

one exposure to the various test stages. It should be noted, however, that 10 of the 32 subjects in the four experiments of the present study passed through each phase without any retraining or retesting. These results are even more interesting when one takes into account the following three factors. First, the B stimuli involved in direct training were never presented together with the tested C stimuli and tested D (positive and negative) stimuli. Thus, these transfer effects cannot be readily explained on the basis of direct association established by simultaneous presentation. Second, predetermined stability criteria were employed during the test stages that allowed for nonpredicted performances. It is unlikely, therefore, that the present results were generated mainly by extraneous feedback effects arising from extensive retraining and retesting. Third, none of the subjects were exposed to any matching-to-sample equivalence test trials before the transfer-of-control test. In effect, a matching-to-sample equivalence test was not necessary in order to obtain the predicted transfer of functions through the equivalence and other derived relations.

The present findings are in accordance with two experiments from a recent study (Hayes et al., 1991). In Experiment 2 of Hayes et al., a transfer of consequential functions through "genuine" equivalence relations was shown without a prior matching-to-sample equivalence test, and in Experiment 4, a blind recycling procedure was used to control for extraneous feedback effects (subjects were trained and tested twice and the second test performance was accepted as final). However, it is important to note that these two procedures were not employed simultaneously in a single experiment (i.e., in Experiment 4 all subjects were tested for equivalence before being exposed to the blind recycling procedure, and in Experiment 2 1 of the 4 subjects was exposed to five separate transfer tests before the predicted performance emerged). Thus, the present study extends the Hayes et al. (1991) findings both by using transfer test stability criteria *and* by demonstrating a transfer of functions without a standard equivalence test within the same experiments. Furthermore, the present study is the first to show a transfer of functions across derived physical similarity and derived negative relations.

Why were the present procedures so efficient in generating the predicted transfer of functions? One possibility is that the extensive and detailed verbal instructions delivered to the subjects might have played a major role in generating the consistent performances. However, the role of verbal instructions in transfer studies remains unclear. For example, in one previous transfer study (Wulfert & Hayes, 1988), detailed instructions were used that, unlike the instructions employed here, explicitly specified the relationship between the conditional discrimination and transfer-of-function tasks. However, even with these instructions, 4 of the 8 subjects did not show an immediate transfer of functions and were exposed to partial matching-to-sample equivalence tests *before* the predicted transfer-of-control performances emerged. Furthermore, recent evidence (Green et al., 1991) suggests that subjects exposed to detailed and extensive instructions may show a transfer of functions less readily than subjects who are provided with minimal instructions. Such findings indicate that the effects of verbal instructions in equivalence and transfer studies should be subjected to careful experimental examination, and their "transfer-generating" effects should not be taken for granted.

Another factor that could have played a role in the success with which the present procedures generated a transfer of functions may be as follows. Unlike a number of previous transfer studies (e.g., Green et al., 1991; Hayes et al., 1987, 1991; Wulfert & Hayes, 1988), the current procedures presented the conditional discrimination tasks used during training on alternate trials with the transfer-of-control tasks (in the previously cited studies, the conditional discrimination and transfer tests were presented in discrete blocks of trials). This continued exposure to the conditional discrimination tasks during transfer testing may have been, in some undefined way, discriminative for transfer-of-control responding. More informally, subjects would have been more likely to "see the connection" between the matching-to-sample and schedule performance trials and would have had less difficulty "remembering the correct relations" when they were presented concurrently during the test phases. It should be noted, however, that in two other transfer studies, which interpolated conditional discrimination training trials and transfer-of-function trials, the predicted transfer of control did not emerge for any subject before more than one exposure to the critical test session or, in the case of 1 subject, exposure to a standard equivalence test (de Rose, McIlvane, Dube, Galpin, & Stoddard, 1988; de Rose, McIlvane, Dube, & Stoddard, 1988). Therefore, it appears that simply interpolating conditional discrimination and transfer-of-control trials is not sufficient to produce the highly reliable and often rapid transfer of functions observed in the present study.

At present, it is not possible to say whether the explicit verbal instructions, alternating conditional discrimination tasks with the transfer tasks, a combination of these, or some other variable was responsible for the reliable transfer of control seen here. Furthermore, given that this is the only study of transfer that has employed time-based schedule responding as discriminative responses, we cannot rule out the possibility that unspecified properties of these discriminative responses played a crucial role in the observed transfer of functions. Clearly, future researchers working in this area need to consider (a) the role of verbal instructions, (b) the effects of different testing procedures, and (c) the possible differential effects of various discriminative responses. Until the differential effects of these and other factors (e.g., the use of young or developmentally disabled populations) have been examined in detail, we should be cautious when comparing results from different transfer studies in which these factors differ across experimental procedures.

Derived Nonarbitrary Relations

The present study (Experiments 2 and 4) showed a reliable transfer of control through equivalence and physical similarity. The present results, therefore, extend the previous findings of Fields et al. (1991) by demonstrating that a transfer of functions can also occur, through equivalence and physical similarity, when the transfer of control is derived from a matching-to-sample preparation to a schedule control context. However, one criticism of the current procedures might be that the use of nonsense syllables, in contrast to the lines employed by Fields et al. (1991), does not allow us to specify exactly the controlling properties of the observed transfer through physical similarity. Specifically, the physical similarity test stimuli were made different by changing the vowel in the consonant-vowel-consonant letter sequence. Thus, it is not clear whether responding was under the control of the consonants only, the sound of the verbalized syllables, or a combination of these and/or other stimulus properties. Perhaps future studies could combine the present procedures with those outlined by Fields et al. (1991) in order to examine more closely the stimulus properties that may control a transfer of functions through derived physical similarity across two different testing contexts.

Derived Relations Through S− Control

The present study is the first to show a transfer of functions through a derived negative relation. These findings suggest that the transfer-of-functions phenomenon may be a particularly powerful behavioral process. Not only is it possible for subjects to show a derived transfer of control within an equivalence class, but it is also possible for them to show a transfer for control on the basis of derived S− relations between equivalence classes. However, many questions remain. For example, in the present study only two types of schedule performances were trained (high rate and low rate); thus, the present findings are limited to this forced-choice context. One possible direction, therefore, would be to use the current procedures to examine the effects of training a third type of performance in the presence of a novel stimulus during discriminative function training (i.e., B1 = low rate, B2 = high rate, and NS = medium rate). Perhaps some subjects provided with this third response option would then emit the medium rate in the presence of the two S− stimuli (ND1 and ND2) during test stages, instead of showing the currently observed transfer of functions across the two equivalence classes. In other words, it may be possible to create a third stimulus class (i.e., NS, ND1, ND2), with appropriate discriminative functions, on the basis of S− relations. This possibility warrants further attention.

Matching-to-Sample Tests

The matching-to-sample tests (Phase 4) showed that all subjects immediately produced performances that were in complete accordance with the previously derived transfer of functions. The reliability of these data contrasts with those of an earlier study that reported a transfer of functions without subsequent equivalence responding on matching to sample (Sidman, Wynne, Maguire, & Barnes, 1989). It is important to note, however, that these researchers exposed subjects to a history of explicit reinforcement for transferring discriminative functions through functional classes, and thus the transfer effects can be accounted for in terms of directly established stimulus control (Hayes, 1989). The relation between equivalence and functional classes is a complex issue and is not yet fully understood (Hayes, 1989; McIlvane & Dube, 1990; Sidman et al., 1989; Vaughan, 1989). The issue is particularly complicated because functional classes can sometimes lead to equivalence relations (Sidman et al., 1989). The present results, therefore, should be seen as indicating that derived relations on matching to sample are likely, but not certain, after a derived transfer has been shown. Indeed, caution is especially important here, because an appropriate transfer performance does not always follow equivalence responding (e.g., de Rose, McIlvane, Dube, & Stoddard, 1988; Green et al., 1991). At the present time, it seems best simply to note any major differences between the current procedures and those reported in previous studies, while recognizing that the relations among equivalence, functional classes, and transfer effects require further experimental and theoretical attention.

Conclusion

The present research demonstrates that the equivalence paradigm may be usefully employed in the experimental analysis of stimulus control over human schedule performance. However, insofar as equivalence can occur without an appropriate transfer of functions, equivalence cannot offer a complete explanation of the present results. Furthermore, even if equivalence was accepted as an explanation, it would then be necessary to explain equivalence itself (Barnes & Holmes, 1991; Hayes, 1991). One solution to this problem may involve explaining both the equivalence and derived transfer of functions observed here by appealing to the subjects' well-developed verbal abilities. Subjects' verbal reports typically showed that they could describe the derived stimulus relations and the appropriate discriminative functions of the stimuli. However, if we accept the importance of verbal ability, we must then explain how such verbal skills develop in the first place and how these skills generate equivalence and derived transfer effects.

Two major theoretical accounts have been offered that attempt to deal effectively with these issues. The first account, proposed by Sidman (1990), circumvents the problem of explaining verbal ability by viewing equivalence as a fundamental stimulus function that may itself underlie certain language skills. According to this account, a derived transfer of functions is produced when "equivalence relations transfer new stimuli—for example, words—into already existing functional classes" (Sidman et al., 1989, p. 273). In effect, a derived transfer depends upon the interaction of two separate behavioral processes, both of which may operate independently. The second account, proposed by Hayes (1991), views verbal ability as being essentially synonymous with equivalence and derived transfer effects, and suggests that all three can be explained in terms of a history of arbitrarily applicable relational responding (transfer effects generated by a history of explicit reinforcement are seen as representing a distinct, nonverbal behavioral process). From this perspective, derived relations on matching to sample and a transfer of functions through those relations may be under the control of separate contextual stimuli (Hayes, 1991, pp. 23–27), and therefore in certain contexts matching-to-sample and transfer test performances will necessarily diverge (see Wulfert & Hayes, 1988). This may occur, for example, when the matching-to-sample format itself acts as a contextual cue for equivalence relations, but the transfer test does not. In summary, neither of these theoretical accounts considers equivalence a complete explanation for derived transfer effects, and both are generally consistent with the idea that matching to sample and transfer tests may sometimes produce apparently contradictory performances. Therefore, only future research will determine whether one of these accounts, or perhaps a third alternative, will provide the most effective way of talking about the types of phenomena observed in the present study.

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